CRUSTAL GROWTH AND REWORKING ALONG THE ANTARCTIC PENINSULA: AN ISOTOPIC APPROACH

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RESUMEN

Se Compara las características de isotopes de Nd y las edades modeladas ("model ages") de rocas igneas relacionadas a subduccíon de la Peninsula Antarctico, a datos publicados de la Cordillera Andina. Se relaciona variaciónes en las edades modeladas, en tiempo y tambien en espacio, a la evolución tectonica de partes diferentes del margin pacifico de Gondwana, anteriormente conjuntadas.

Antarctic Peninsula, subduction-related magmatism, neodymium isotopes, model ages.

Introduction

Continental destructive plate margins are the most important sites of continental crustal growth in the geological record. During subduction-related magmatism, a variety of different geochemical reservoirs may be tapped, and it is generally accepted that subduction-related magmas may contain contributions from depleted mantle, continental crust, variably enriched continental lithospheric mantle, subducted terriginous and pelagic sediments, and the products of slab de-watering. Variable amounts of interaction between the above geochemical reservoirs leads to the geochemical diversity of magmas erupted at active continental margins. However, because some of the above components have similar trace element and isotopic characteristics (e.g. terriginous sediment derived from subduction-related granitoids) determining the contributions from each component may be problematical.

Neodymium isotope systematics, and in particular neodymium 'model ages' have been utilised by a number of workers to give a broad overview of the relative contributions from depleted mantle and crust to magmas during arc evolution, and to separate paeriods of intracrustal re-working from the growth of new crust from the mantle (e.g. DePaolo, 1981; Miller & Harris, 1989).

In this study, we investigate temporal and spatial variations in the Nd-isotope characteristics of arc-related rocks from the Antarctic Peninsula, which was the site of almost 200 Ma of continuous subduction-related magmatism and formed part of the Pacific margin of Gondwana. Previously published geochronological and elemental data along with new isotopic data allow the identification of intrusive rocks which were generated from depleted mantle sources as well as material which clearly represents anatectic melts of pre-existing crustal rocks. The relative contributions of depleted mantle and lithosphere to magmatism can therefore be assessed. We present 83 previously unpublished Nd-isotope analyses supplemented by 50 published analyses of a variety of arc rocks, including pre-subduction gneissose basement, metasedimentary and sedimentary rocks from the accretionary prism complex and back-arc basin and post-subduction alkali basalts. From this data, and by comparison with published analyses for the central Andes, we demonstrate that similar processes of magmagenesis involving similar source compositions (depleted mantle and continental crust), occurred in different parts of the supposedly contiguous Pacific margin of Gondwana but at different times.

Geochronology.

The majority of the exposed geology of the Antarctic Peninsula can be accounted for by processes related to easterly-directed subduction of oceanic crust beneath the peninsula from during the Mesozoic and Cenozoic. Geochronological studies on undeformed granitoids record more than 200 Ma of subduction-related magmatism in parts of the Antarctic Peninsula (Pankhurst, 1982). The oldest reliably dated rocks in the area are mid-Palaeozoic granitoids which have yielded isochrons indicating emplacement at 408 8 Ma (Milne & Millar 1989). Occurrences of migmatitic gneisses do not yield a well-constrained age, but their Sr-isotope characteristics are suggestive of formation at around 600 Ma (Hole et al., 1991). Carboniferous granitoids are also known, and there is some evidence to suggest that subduction may have occurred for at least part of the Palaeozoic (Milne & Millar 1989). However, the most volumetrically important rocks exposed are Late Triassic (c. 214 Ma) to Tertiary (c. 48 Ma) plutonic and extrusive rocks (Pankhurst et al., 1988).

The oldest known sedimentary rocks in the region are the paragneisses of central eastern Graham Land, which were metamorphosed to amphibolite grade during the Carboniferous (Milne & Millar 1989). During the Mesozoic, sedimentation occurred in both fore-arc and back-arc settings as well as in the accretionary prism complex. Accretionary prism metasedimentary rocks of the Trinity Peninsula Group are thought to be Permo-Triassic in age, and back-arc sedimentation in the James Ross Island area was intiated during the Middle-Late Cretaceous.

Nd-isotope systematics of crust and mantle: Model ages

The most commonly used Nd-model age (T_{DMUR}:depleted mantle uniform resevoir) is based on the period of time since the elemental Nd in a sample was last in isotopic equilibrium with an assumed depleted mantle source region. Thus, if the model age of a sample is the same as its stratigraphic age (time of emplacement for granitoids), then it must be have been derived from depleted mantle at that time, whereas a model age that is significantly greater than the stratigraphic age (as is the case for the majority of subduction-related granitoids) implies that intracrustal processes may have been important during the formation of that sample; the greater the discrepancy between the model and stratigraphic ages, the greater the likely importance of intracrustal processes and the longer the 'crustal residence time' of that sample.

It has recently been noted by a number of workers that during the fractional crystallisation of granitic rocks, minor phases such as allanite, zircon and monazite may cause significant fractionation of the REE, often resulting in increasing Sm/Nd ratios with increasing degree of fractionation (e.g. Miller & Harris, 1989; Pimentel & Charnley 1991). This is clearly a major problem in calculating model ages and prevents the projection of $^{143}Nd/^{144}Nd$ ratios beyond the stratigraphic age of the sample. Miller & Harris (1989) circumvented this problem of "resetting" of model ages during magmatic fractionation by calculating the model age of silicic rocks using an assumed average crustal Sm/Nd ratio of 0.19. Here, we have refined this method of back calculation by using the present-day Sm/Nd ratio of acid rocks to calculate the $^{143}Nd/^{144}Nd$ ratio at the time of emplacement (i.e. the initial $^{143}Nd/^{144}Nd$ ratio), and from that point back to the growth line for DMUR, $^{143}Nd/^{144}Nd$ ratios are calculated using the average crustal $^{147}Sm/^{144}Nd$ ratio of 0.12, approximately equivalent to an Sm/Nd ratio of 0.2.

Temporal variations in Nd-isotope geochemistry.

The variation in $^{143}Nd/^{144}Nd$ (expressed as ENd_t) through the Phanerozoic for Graham Land is presented in Fig. 1. Samples from Graham Land define a 'U'-shaped trend between 420 Ma and the present-day. Between 290 and 150 Ma, all samples have ENd_t more negative than -2.0. However, both before and after this period samples have positive ENd_t values and there are clear trends of decreasing ENd_t from 420 Ma to 180 Ma and increasing ENd_t from 180 Ma to the present day. The model age at time of emplacement (MATE) is the difference between calculated two-stage model ages and known stratigraphic age. In Fig. 2. MATE is plotted against stratigraphic age. On this diagram any rock derived soley from depleted mantle will plot on the x-axis, as the effect of mantle evolution through Phanerozoic time is removed. The model age of the Nd in an individual sample at the time of emplacement is the best estimator of the relative contributions from depleted mantle and crust during magmagenesis. A low MATE value indicates limited involvement of significantly older continental lithosphere during the genesis of an individual sample, whereas a high MATE value gives a minimum model age of the re-worked continental crust.

What is apparent from this study is that the influence of a crustal source-region increased throughout the late Palaeozoic upto a maximum in the Middle Jurassic. It is also clear that the greatest influence from depleted mantle i.e. samples with the youngest model ages (MATE=0.3-0.7 G.y.), occurred during the mid-Palaeozoic and Tertiary, culminating in the eruption of the Late Cenozoic (7-0.1 Ma) post-subduction alkali basalts. Therefore, the most important periods of formation of new crust from depleted mantle were during the late Paleaozoic and Tertiary, whereas during the Late Triassic and Middle Jurassic magmas underwent significant interaction with pre-exisitng crustal sources. These differences appear to be controlled by large-scale tectonic processes. A period of steep slab dips and associated intra-arc extension during the late Createaceous resulted in the generation of granitoids from dominantle deplteds sources, whereas shallower slab-dips in Triassic-Jurassic times resulted in a broad shallow zone of partial melting in the mantle wedge which may may have provided far greater potential for crust-mantle interactions.

Miller & Harris (1989) showed that during the late Palaeozoic, orogenesis in the Central Andes was predominantly by intracrustal re-working. During the Jurassic, a change in tectonic style resulted in the onset of crustal growth before a return to predominantly intracrustal processes in the last 30 Ma. This is illustrated in Fig. 2. Some notable features of this diagram are that both the maximum crustal residence times, and range in residence ages, are broadly similar for the Antarctic Peninsula and Central Andes. A major difference between the two regions is that the maxima of crustal growth and intracrustal reworking appear to have occurred at different times, and so the evolution trends appear to be 'out of phase'.

Clearly, the significant differences in the timing of intracrustal reworking along the Pacific margin of Gondwana, suggests that although the Andes and Graham Land may have been a contiguous arc at that time, tectonic processes were diachronous along its length, and as at the present-day, along-arc variations in the age, thermal structure and angle of dip of the subducting lithospheric slab may show considerable variations along a single continental convergent plate margin. Indeed, Miller & Harris (1989) suggested that crustal growth at continental margins may progessively decelerate during arc evolution. This conclusion is in contrast to the Antarctic Peninsula where crust growth clearly accelerated with arc maturity.

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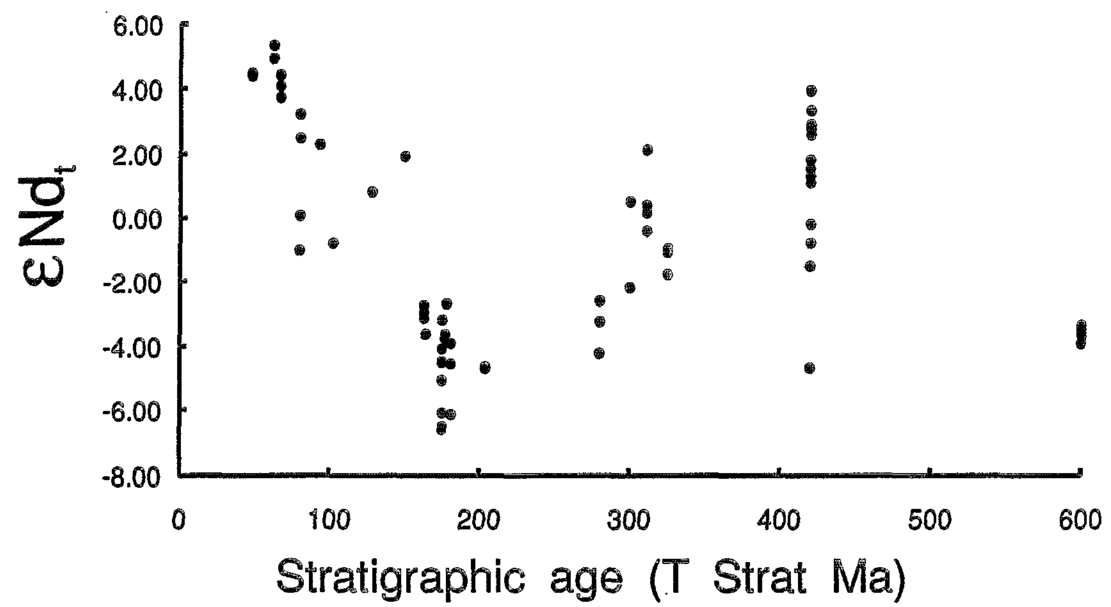
Fig.1


6.00
4.00
2.00
0.00
-2.00
-4.00
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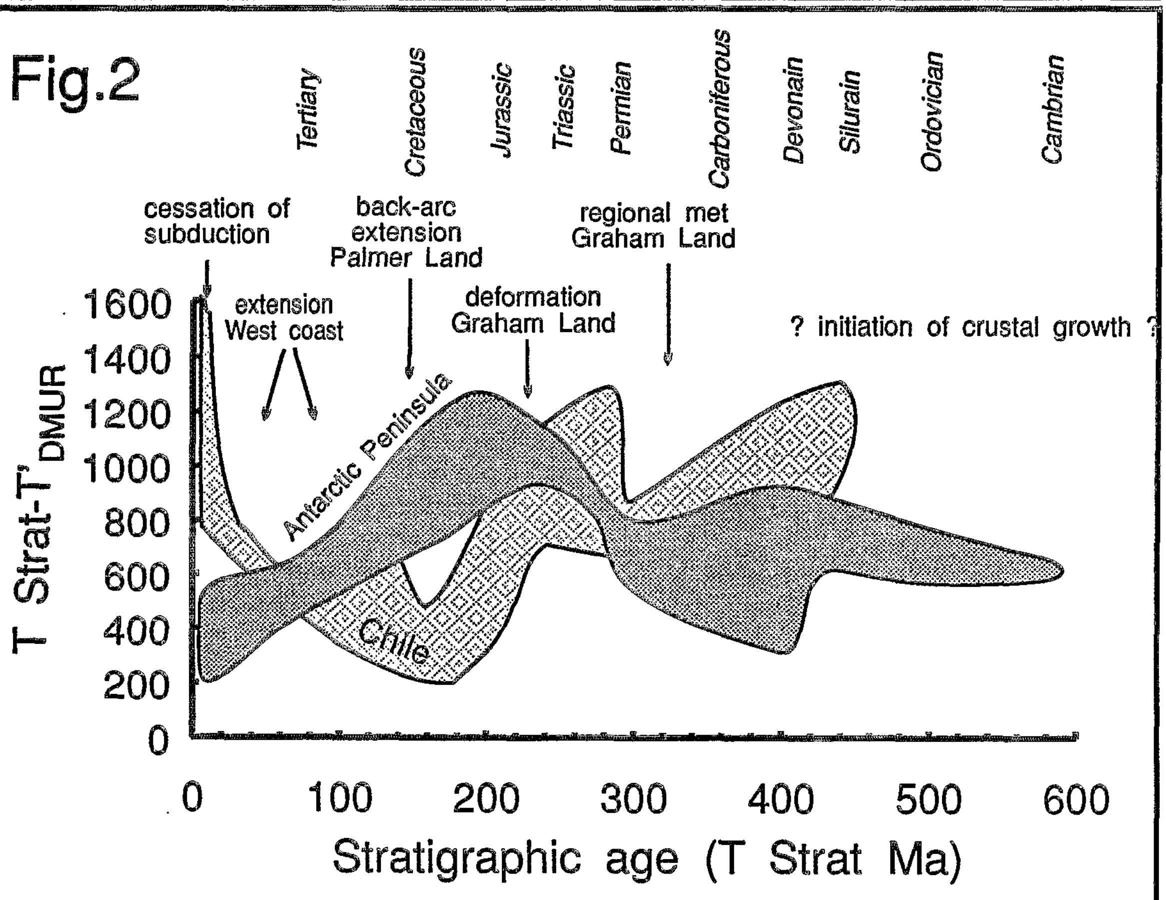
εNd_t
0
100
200
300
400
500
600
Stratigraphic age (T Strat Ma)

Fig.2


Tertiary
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonain
Silurain
Ordovician
Cambrian
cessation of subduction
back-arc extension Palmer Land
regional met Graham Land
extension West coast
deformation Graham Land
? initiation of crustal growth ?
Antarctic Peninsula
Chile
1600
1400
1200
1000
800
600
400
200
0
T Strat-T'DMUR
0
100
200
300
400
500
600
Stratigraphic age (T Strat Ma)